ван критерий оценки износа единичных резцов долота в целом в зависимости от времени бурения различных пород и конструкции долота. На основе экспериментальных данных построена функция износа единичных резцов и долота в целом. Определены требования к конструкции инструмента, которые обеспечивают увеличение времени использования долота.

Научная новизна. Рационализация описания процесса износа как единичных резцов, так и долот в целом, а также разработка критерия оценки износа долота позволяет оптимизировать конструкцию инструмента.

Практическая значимость. Предложен метод определения вероятности величины износа долот в зависимости от времени бурения, разбуриваемых пород и конструкции долота.

Ключевые слова: *интенсивность износа, буровые долота типа PDC, вероятность, проходка, механическая скорость бурения, надежность, регрессия, вероятностная модель*

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EVALUATION OF THE ADEQUACY OF THE STATISTICAL SIMULATION MODELING METHOD WHILE INVESTIGATING THE COMPONENTS PRESORTING PROCESSES

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ОЦІНКА АДЕКВАТНОСТІ МЕТОДУ ІМІТАЦІЙНОГО СТАТИСТИЧНОГО МОДЕЛЮВАННЯ ПРИ ДОСЛІДЖЕННІ ПРОЦЕСІВ РОЗБРАКУВАННЯ ДЕТАЛЕЙ

Purpose. Evaluation of the adequacy of the statistical simulation modeling method developed for examining the measurement error effects on the results of components presorting while their acceptance inspection.

Methodology. Parameters of components presorting calculated by statistical modeling method are compared with parameters of presorting which were determined by common alternative methods:

- graphic-analytical – according to the National Standard ГОСТ 8.051-81 (appendix 2);
- numerical integration of definite integrals in the equations of the mathematical model of the process.

Findings. For the purpose of the measurement error distributions according to the normal law as well as equal probability law it is shown that the calculated parameters do not differ significantly from the parameters listed in the standard. Thus the adequacy of the statistical simulation modeling method is confirmed.

It was found that the method is distinct in simplicity of calculations on a PC, clearness of the obtained results and the possibility of their accurate interpretation.

The statistical simulation modeling method can be used for modeling of both random and systematic measurement errors.

Originality. The mathematic models and statistical simulation modeling methods of acceptance inspection of the geometries of components and calculation of the parameters of their presorting are developed.

Practical value. On the basis of the developed mathematical models, the guidelines on the computer modeling using the method of Monte Carlo presorting processes during the acceptance inspection are compiled. The realization is carried out on the basis of Microsoft Excel program. Methodical instructions are used in academic activities. They can be used in the process of drafting business plans for making decisions during pre-production, which is characterized by a stochastic character, including for the purposes of enterprises of mining machinery.

Keywords: *acceptance inspection, statistical modeling, presorting, measurement error, adequacy*

Problem formulation. Quality of engineering products equally depends on technology of its manufacturing and control effectiveness. Prestart passive acceptance control is widely used by manufacturers and consumers of production. The components or their geomeytrical elements are sorted into accepted and non-acceptable ones during the reception control.

Measurement error of components controlled geometrical parameters leads to acceptance of compo-

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nents, which are considered as corresponding to the accepted tolerance, however the true deviation is out of its limit. The same way some number of components, with dimentions inside the tolerance zone, but close to limits, are faultily recognized as defective. The measurement error influences negatively the technical and economic indices and leads to unjustified excessive costs.

Analysis of recent researche and publications. The detailed analysis of publications, which describe design methods for components presorting probabilistic. characteristic for different distribution forms of parameters measured and measurement error, is shown at the work [1, 2]. It is mentioned that the complication of the probabilistic characteristic calculation is in calculation of multivariate integrals at analytical form even for the easiest laws of distribution.

Approximate calculative methods are graph-analytic and tabulated ones.

The main disadvantage of these methods is inadmissible level of calculation errors of component presorting probabilistic characteristic (up to 10%).

Later numerical methods were suggested, including the method based at factorizing to Taylor series density of distribution of parameter controlled within tolerance limits, and matrix technique. At the work mentioned the particularized program based at Delphi 7 is suggested for estimating of the quantity of wrong accepted and wrong rejected details.

So, today the common control calculating methods of probability characteristics are used for different kinds of distribution law of parameter measured and measurement error or in the form of bulky analytical expressions, numerous tables, diagrams, or on terms of using of speciality application-dependent software.

Not previously solved issues of main problem to which the article is devoted. To overcome the mentioned difficulties, authors suggested to use simulation statistic method, adapted for components or their elements presorting processes and realized by Microsoft Excel program.

The positive results were partially published earlier [3]. At the same time the questions of comparison with the National Standard ГОСТ8.051-81 recommendations and adequacy of method developed were not considered in literature.

Task description. The tasks of this article are:

1. To determine indices used with simulation statistic methods, which characterize the accuracy of component technical producing process and measurement error according to the National Standard ГОСТ 8.051-81 recommendations (apprndix 2).

2. To compare calculated quantities of wrongly accepted and wrongly rejected details with the same facts, which the Standard mentioned contains and to estimate adequacy level of the method developed.

In fig. 1–2 the common (National Standard ГОСТ 8.051-81) dependences of indices *m* and *n* from technology accuracy are shown, where:

m – number of accepted components (percentage), whose measurements are out of tolerance zone limits and accepted as suitable (wrongly accepted);

n – number of rejected details (percentage), whose measurements are within limit parameters (wrongly rejected).

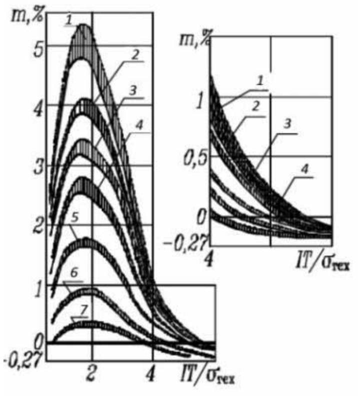

Fig. 1. Common dependence index "m" on technology accuracy index IT/σ_{mex} while different value of parameter $A_{MET(\sigma)}$: 1– $A_{MET(\sigma)}$ =16%; 2 – $A_{MET(\sigma)}$ = 12%; 3 – $A_{MET(\sigma)}$ = 10%; 4 – $A_{MET(\sigma)}$ = 8%; 5 – $A_{MET(\sigma)}$ = 5%; 6 – $A_{MET(\sigma)}$ = 3%; 7 – $A_{MET(\sigma)}$ = 1,6%

To use the graphs we should calculate the ratio:

- IT/σ_{Tex} – technology precision factor, where IT is tolerance value, σ_{Tex} – standard deviation of the components' demensions;

- $A_{MET(\sigma)} = (\sigma/IT)\cdot 100$, where σ – standard deviation of measurement error.

Description of main investigation material with proving of the obtained results. Simulation statistic modeling of presorting processes are made as applied to shaft $\varnothing 100h6(_{-0.022})$ production, because this example is shown at appendix 2 to the National Standard ГОСТ 8.051-81.

Let us suppose, that acceptance limits concur with limit deviation: upper ($es = 0$μm) and lower ($ei = -22$μm). In this case the tolerance IT is equal $es - ei = 22$μm.

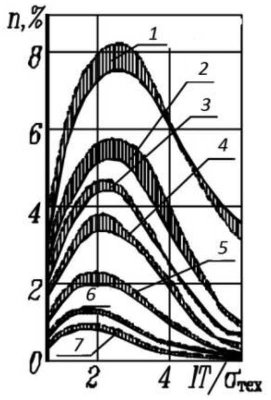

Fig. 2. Common dependence index "n" on technology accuracy index IT/σ_{mex} while different value of parameter $A_{MET(\sigma)}$: 1 – $A_{MET(\sigma)}$ = 16%; 2 – $A_{MET(\sigma)}$ = 12%; 3 – $A_{MET(\sigma)}$ = 10%; 4 – $A_{MET(\sigma)}$ = 8%; 5 – $A_{MET(\sigma)}$ = 5%; 6 – $A_{MET(\sigma)}$ = 3%; 7 – $A_{MET(\sigma)}$ = 1,6%

The method is realized in Microsoft Excel software, using additional function “Analysis package”. The electronic table is created. Its separate fragments are shown in table 1. The table lines show the results of component production and measurements modeling. The columns show the results of statistic modeling. Therefore Electronic table is simulation statistic model of component measurement and control.

Suppose that in column *2* the true deviation values from rating value are modelled. In real conditions of measuring there is no possibility to do that.

In the dialog box from “Analysis Tool Pack” – “Random Number Generation” fill in the following margins:

- number of Variables – 1 (variable is one – true deviation from rating value);
- number of Random Numbers – 5000 (Sample Size);
- distribution – normal (suppose, that there is no dominating factors, which influence deviation from average value);
- distribution parameters: average value (average) and standard deviation (stdev).

Table

Electronic table of simulation statistic modeling of the production, control and presorting process of shaft ∅ 100h6 (to reduce the table volume part of lines is not shown)

Works order number	True deviation of shaft diameter from rating value, μm	Shaft validness estimating	Random measurement error, μm	Real deviation (taking into account the error of measurement) of the shaft from rating value, μm	Assessment of suitability details by results of measurement	Presorting results			
						Right rejected	Wrong rejected	Right accepted	Wrong accepted
1	*2*	*3*	*4*	*5*	*6*	*7*	*8*	*9*	*10*
Shaft 1	-14,0	1	5,0	-9,0	1	0	0	1	0
Shaft 25	-3,6	1	4,3	0,7	0	0	1	0	0
Shaft 26	-17,1	1	1,3	-15,8	1	0	0	1	0
Shaft 320	1,4	0	-2,6	-1,2	1	0	0	0	1
Shaft 4997	1,4	0	-2,6	-1,2	1	0	0	0	1
Shaft 5000	-5,5	1	2,5	-3,0	1	0	0	1	0
Sum total details at column *3*		4743	Sum total details at column *6*		4086	502	412	3935	151
Sum total at column *3*, %		86,94	Sum total at column *6-10*, %		81,72	10,04	8,24	78,7	3,02

Average value of deviation from rating value is taken as equal to the coordinate of center of tolerance zone, μm

$$e_m = \frac{es+ei}{2} = \frac{0+(-22)}{2} = -11.$$

High level of tuning of technological production process is supposed. Also, the low level of tuning can be modeled. High level of tuning of technological production process is supposed.

Standard deviation cam be modeled for technological processes, which differ by accuracy level:

- lower accuracy, when the ratio of tolerance zone value *IT* to standard deviation σ_{TEX} is less than 6;
- normal accuracy (ratio of of IT/σ_{Tex} is equal to 6);
- higher accuracy (ratio of IT/σ_{Tex} is more than 6).

In the example from table 1 lower technology accuracy level is accepted, when the ratio mentioned is equal to 3 (to compare with data in fig. 1–2).

Then standard deviation will be, μm

$$\sigma_{\text{TEX}} = \frac{IT}{3} = \frac{22}{3} = 7{,}33\,.$$

The results of statistical modeling of shaft deviation from rating value in case of measurement zero error are in column *2*. Capacity of values is 1 digit after comma, that is 0,1 μm, which is enough for accuracy of modeling deviation from rating value.

In column *3* the shaft acceptability is estimated by 2 point scale: acceptable components get point β_{tr} = “1”, and unacceptable once get point β_{tr} = “0”. True deviation value from the rating value of the good detail e_{tr} is within tolerance zone.

So to complete column *3* electronically we use the formula

$$IF(es >= e_{tr} >= ei;1;0)\,,$$

where e_{tr} is true deviation from the rating value.

The sum of points in column *3* (4743) shows the part of valid components for selected accuracy of technology for modeling.

In column *4* measuring error of the shaft is modeled. For modeling the "Analysis Tool Pack" – "Random Number Generation" is used, too. Filling the corresponding margins:

- number of Variables –1 (variable is one – true deviation from the rating value);
- number of Random Numbers –5000 (Sample Size);
- distribution – normal (suppose, that there is no dominating factors, which influence at deviation from the average value).

In the process of further research, the uniform distribution was used for modeling random error. It is recommended to use this approach, when there is no authentic facts about the kind of distribution.

Column *5* contains total results of measurement (measurement error is not equal 0) deviation from the rating value. Here we sum up the results line from corresponding cells of columns *2* and *4*.

In column *6*, the component acceptance estimation is done by results of measurement taking into account the error. Valid components get point β_{ad} = "1", and unacceptable ones get point β_{ad} = "0". Real deviation value from the rating value of the valid component e_{ad} is within the tolerance zone. The point is determined, using formula

$$IF(es >= e_{ad} >= ei;1;0),$$

where e_{ad} is real deviation from the rating value.

The sum of points in column *6* (4086) shows the part of valid components for selected accuracy of technology taking into account measurement errors. The difference between sums in columns *3* and *6* demonstrates measurement error reduction (in our example for 5,2%).

Then percent of wrongly accepted and wrongly rejected components is discovered. For that, we use formulas, which show logical conditions:

- rightly rejected details should have point "0" in column *3* and *6*;
- wrongly rejected details should have point "1" in column *3* and point "0" in column *6*;
- rightly accepted details have to have point "1" in columns *3* and *6*;
- wrongly accepted details should have point "0" in column *3* and point "1" in column *6*.

Statistic modeling results are shown in the last line of the imitation table at crossing with columns *6–10*. In our example it is m = 3,02% and n = 8,24%.

To determine the sample size adequacy, confidential interval value was calculated when estimating index m and n for different quantity of details. It is defined that calculations accuracy of m and n depends on the sample size and 1000 is enough for it. It corresponds to the central limit theorem in statistics.

In fig. 3–6 point estimations of presorting indices m and n are shown, which were calculated by statistical modeling method for normal and uniform distribution of random measurement error versus the National Standard ГОСТ 8.051-81 graphs.

Diagrams in fig. 5–6 show that the results differ by a decimal of percent. The main reasons for the insignificant difference are:

- Diagram curves at approximate the calculated data, found by numerical integration method, and that is why they do not intersect at the considered points.
- The authors of the National Standard applied home displacement by ordinate axis at 0,27% (for index m diagram).
- Displacement leads to the negative value of index m, which does not correspond to the physical meaning of the index, because part of wrongly accepted details cannot be negative.

Due to this it is possible to maintain that simulation statistical modeling method allows to estimate presorting indexes more accurately than the graphic-analytical method which is described in the appendix to the National Standard ГОСТ 8.051-81.

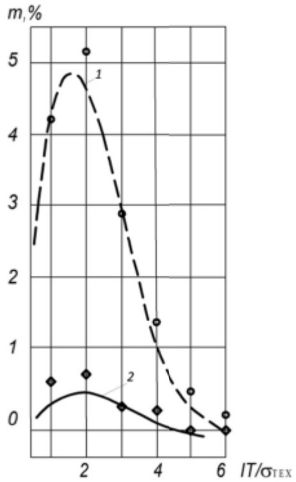

Fig. 3. Point estimation of presorting index m for the normal distribution law of random measurement error if: 1– $A_{МЕТ(\sigma)}$ = 16%; 2 – $A_{МЕТ(\sigma)}$ = 1,6%

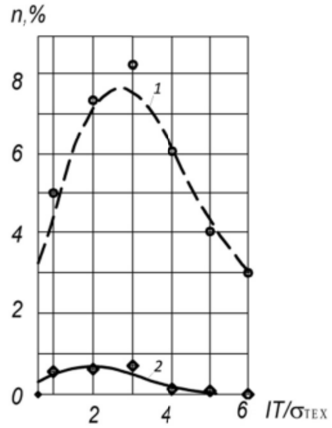

Fig. 4. Point estimation of presorting index n for the normal distribution law of random measurement error if: 1– $A_{МЕТ(\sigma)}$ = 16%; 2 – $A_{МЕТ(\sigma)}$ = 1,6%

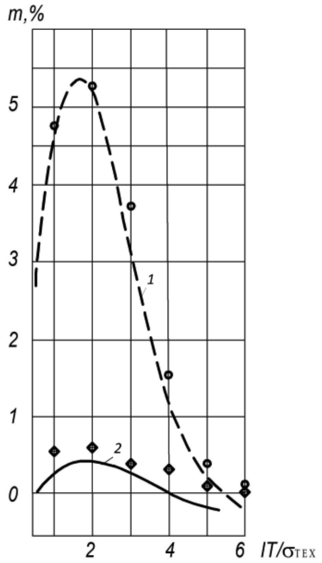

Fig. 5. Point estimation of presorting index m for the uniform distribution law of random measurement error if: 1– $A_{МЕТ(\sigma)}$ *= 16%; 2 –*$A_{МЕТ(\sigma)}$ *= 1,6%*

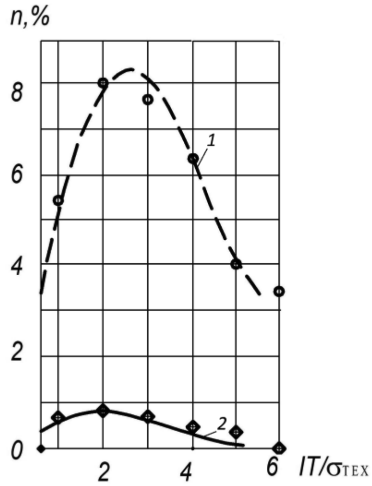

Fig. 6. Point estimates of presorting index n for equal distribution law of random measurement error if: 1– $A_{МЕТ(\sigma)}$ *= 16%; 2 –*$A_{МЕТ(\sigma)}$ *= 1,6%*

Resume and prospects for future developments in thes direction.

1. Adequacy of statistic modeling method is confirmed, because calculated indices *m* and *n* do not essentially differ from parameters of the National Standard 8.051-81 for distribution of random error for the normal law and equal probability law.

2. Simulation statistic modeling method has certain advantages and prospectives, such as:

- the structure transparency of simulation statistic model allows to include additional blocks into the model composition if necessary, which takes into account the new factors of additional properties of the simulated object;

- the obviousness and traceability of modeling results, which essentially increase adequacy of the received results because it allows to analyze influence of every single factor at forming of final result step by step;

- possibility to use this method in describing processes and devices which belong to the adjacent areas of machine-building, for example, to study of problematic aspects of prestart control of tooth gear profile geometrical parameters;

- using built-in Microsoft Office Excel functions which allows to essentially facilitate program realization of investigated simulation statistical model without accuracy losses and as a result reduce requirements for the qualification level of the engaged staff to bachelor level;

- there is no necessity to purchase special high-cost software and engage high-qualified programmers.

3. Simulation statistic modeling method of measurement and control process is implemented into educational process of the National Mining University. It can be used in technological preparation of a new product manufacturing while choosing the corresponding measuring instrument characterized by optimal combination of instrument accuracy and its cost.

4. Further development of simulation statistical modeling method is necessary for:

- using it in researching adequacy of components prestart control quality, which differ by higher constructive and technological complexity, for example, involute gearwheel;

- automation of time-consuming calculation on PC using Office Microsoft Excel or MathCAD software.

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Мета. Оцінка адекватності розробленого методу імітаційного статистичного моделювання, застосованого для вивчення впливу похибки вимірювання на результати розбракування деталей при їх приймальному контролі.

Методика. Обчислені розробленим методом статистичного моделювання показники розбракування деталей зіставлені з показниками розбракування, що одержані відомими альтернативними методами:

- графоаналітичним – за ГОСТ 8.051–81 (додаток 2);
- чисельним інтегруванням визначених інтегралів у рівняннях математичної моделі процесу.

Результати. Показано, що розраховані параметри несуттєво відрізняються від параметрів, наведених у стандарті, для розподілів похибки вимірювання як за нормальнім законом, так і за законом рівної ймовірності. Тим самим підтверджено адекватність методу статистичного імітаційного моделювання.

Встановлено, що вказаний метод відрізняється простотою розрахунків на ПЕОМ, наочністю отриманих результатів і можливістю їх точної інтерпретації.

Метод імітаційного статистичного моделювання може бути досить просто адаптований для моделювання як випадкових похибок вимірювання, так і систематичних.

Наукова новизна. Розроблені математичні моделі та методики імітаційного статистичного моделювання приймального контролю геометричних елементів деталей і розрахунків параметрів їх розбракування.

Практична значимість. На основі розроблених математичних моделей складені методичні вказівки з комп'ютерного моделювання методом Монте-Карло процесів розбракування при приймальному контролі. Реалізація здійснена на основі програми Microsoft Excel. Можливе її застосування при складанні бізнес-планів для прийняття рішень у період підготовки виробництва, що характеризується стохастичним характером, у тому числі й для підприємств гірничого машинобудування.

Ключові слова: *адекватність, приймальний контроль, статистичне моделювання, розбраковування, похибка вимірювань*

Цель. Оценка адекватности разработанной методики имитационного статистического моделирования для изучения влияния погрешности измерения на результаты разбраковки деталей при их приемочном контроле.

Методика. Вычисленные методом статистического моделирования показатели разбраковки деталей сопоставлены с показателями разбраковки, определенными известными альтернативными методами:

- графоаналитическим по ГОСТ 8.051–81 (приложение 2);
- численным интегрированием определенных интегралов в уравнениях математической модели процесса.

Результаты. Показано, что рассчитанные параметры несущественно отличаются от параметров, приведенных в стандарте, для распределений погрешности измерения как по нормальному закону, так и по закону равной вероятности. Тем самым подтверждена адекватность метода статистического имитационного моделирования.

Установлено, что указанный метод отличается простотой расчетов на ПЭВМ, наглядностью полученных результатов и возможностью их точной интерпретации.

Метод имитационного статистического моделирования может быть применен для моделирования как случайных погрешностей измерения, так и систематических.

Научная новизна. Разработаны математические модели и методики имитационного статистического моделирования приемочного контроля геометрических элементов деталей и расчетов параметров их разбраковки.

Практическая значимость. На основе разработанных математических моделей составлены методические указания по компьютерному моделированию методом Монте-Карло процессов разбраковки при приемочном контроле. Программная реализация осуществлена в среде Microsoft Excel. Возможно ее применение при составлении бизнес-планов для принятия решений в период подготовки производства, которое характеризуется стохастическим характером, в том числе и для предприятий горного машиностроения.

Ключевые слова: *адекватность, приемочный контроль, статистическое моделирование, разбраковка, погрешность измерений*

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